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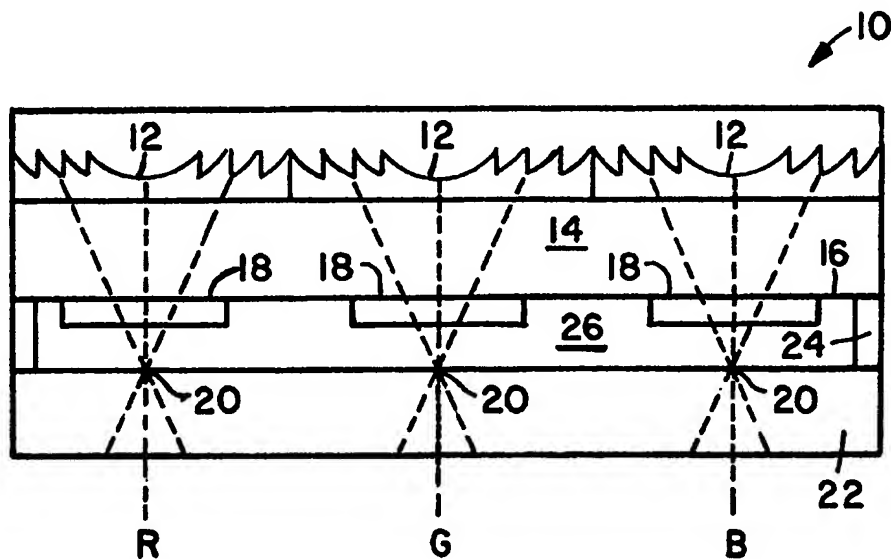
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(54) Title: **LENS ARRAY ON LCD PANEL AND METHOD**



(57) Abstract

A projection LCD comprising a microfresnel lens array (12) on a panel (10), the microfresnel lens (12) being composed of a photoresist having a linear response and being in a structural pattern of a fresnel lens, and a method of increasing the amount of light transmitted through the LCD (10) by using such microfresnel lens array (12).

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LENS ARRAY ON LCD PANEL AND METHOD

FIELD OF THE INVENTION

5 A diffractive element lens array on a LCD panel and a method of production.

BACKGROUND

 An important aspect of the performance of LCD systems is brightness. This is a
10 particularly serious problem in TV systems employing an LCD projection element.
 Light is lost at every stage of transmission. This includes the polarized light source, the
 color filters and the aperturing due to electrical circuitry on the LCD panel.

 The desirability of focusing light to better utilize the available apertures has been
 recognized. It has been proposed to employ a microlens array with each lens
15 corresponding to a pixel in the LCD.

 An early method for forming such an array involved generating a spherical
 surface on one end of a plurality of glass rods. The rods were then combined by
 bundling and fusion sealing. While effective technically, this procedure, obviously, was
 a cumbersome, time-consuming procedure.

20 Another method involves developing a gradient refractive index in a glass. It has
 been proposed to accomplish this by an ion exchange process. Another proposed
 procedure involves impregnating a porous, glass body with a photolyzable material, and
 then exposing the impregnated body with photolyzing light.

...the lens array is independent of the substrate temperature.

It is, therefore, highly desirable to produce the lens array on an arbitrary
15 substrate. This decouples the method of making the lens from the required thermal and
physical properties of the substrate. It can be accomplished by making diffractive
microlenses. Theoretically, the diffractive lens can produce a wavefront that is identical
to a conventional refractive lens.

An approximation to the required structure can be achieved through a technique
20 known as binary optics. In this case, a multi-step approach is used to approximate the
required surface configuration. This is shown in copending application, Serial No.
08/027,412, filed March 8, 1993 in the names of N. F. Borrelli et al. and assigned to the
same assignee as this application. That application discloses and claims an integral cover
glass for an LCD panel. The cover glass has an array of microlenses made by the binary
25 optics approach and integral with the outside of its front face. The microlens array is an
array of diffractive gratings produced in a glass surface by a practice involving a
combination of photolithography and glass etching.

The diffractive microlens made by the binary optic method, satisfies the above
criterion of being substrate independent. However, it requires a number of separate
30 exposure steps, and glass etching steps, to achieve a sufficient level of stepwise
approximation to permit diffraction efficiencies of over 90%. Thus, a theoretical

efficiency of about 95% requires producing eight levels in a diffractive grating, together with the necessary multiple photomask exposures. It would obviously be desirable to provide a simpler procedure. It would also be desirable to employ a lens array having a true Fresnel pattern, that would improve on the performance of the diffractive microlens
5 made by the binary optic method.

The design of, and manner of producing, a microlens array by the binary optics approach presents a further, significant deficiency. It does not permit fully utilizing the available space for a lens, that is, it does not provide what is known as a high-fill factor. This is explained in more detail, infra. It would, therefore, be desirable to provide a
10 microlens array having a design, and a method of production, whereby the lens array has a high-fill factor such that the theoretical efficiency can be 100%.

A triad lens array design, such that each lens is designed to provide a different color, while maintaining a common focal length, would also be desirable. This would enable correction for chromatic aberrations.

15 Finally, it would be desirable to fabricate the lens array on a material having the same properties as the LCD panel glass, preferably on the panel glass itself. Also, it would be desirable to conduct the fabrication process at essentially ambient temperature so that no thermally induced mechanical distortion will occur. Such distortion ultimately could lead to misregistration with the LCD panel.

20 It is a basic purpose of the present invention to provide a microlens array on, or in, an LCD panel. A further purpose is to provide a microlens array that can be fabricated in a manner meeting the needs described above. Another purpose is to provide a microlens array that utilizes a diffractive grating structure to effect the lens function. A still further purpose is to provide unique methods of fabricating a microlens
25 array with high diffraction efficiency. A particular purpose is to provide a unique microfresnel lens array and a method of production.

Literature of possible interest is described separately.

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BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a schematic view of a typical Fresnel lens pattern.

FIGURE 2 is a schematic showing of an optical system for focusing light in an
20 LCD with a microfresnel lens array.

FIGURE 3 is a schematic representation of an alternative optical system for focusing light in an LCD with a microfresnel lens array.

FIGURE 4 is an optical micrograph showing a photomask used in practicing the present invention.

25 FIGURE 5 is a surface trace showing a record of an Atomic Force Microscopy measurement.

FIGURE 6 is a photo taken by optical microscopy showing a microfresnel lens array in accordance with the invention.

BRIEF DESCRIPTION OF THE INVENTION

The present invention arose from a search for an efficient way to improve the light transmittance in a projection LCD TV. It incorporates a high-fill factor
5 microfresnel lens array in an optical system to focus light through the clear region of an LCD pixel. The lens array can be considered as a separate element in operative relation to, or formed in, the outer, or front, face of an LCD panel glass. The thickness of the panel glass corresponds to the focal length of the lenses.

As indicated earlier, known means of providing a lens array have entailed using
10 special glasses. These glasses have different physical properties, particularly thermal expansion coefficient, thereby leading to problems in ultimately maintaining registration with the panel glass. The present invention obviates these problems by forming a diffractive element lens array on, or in direct contact with, the panel glass.

In designing the physical structure of an individual, diffractive lens element, two
15 approaches are available in theory. One is a microfresnel lens array; the other, a binary approximation as described in copending application S.N. 08/027,412. The binary optic approach, although straightforward, has a theoretical diffraction efficiency dependent on the structural levels, as explained earlier. FIGURE 1 shows a typical Fresnel lens pattern that would be reproduced on a micro scale in a microfresnel lens array.

20 The microfresnel lens structure provides a theoretical diffraction efficiency of 100% which is highly desirable. The difficulty with that approach is the need for a means of producing the requisite surface curvature pattern. The present invention solves this problem by producing a microfresnel lens from a transparent photoresist. The photoresist is characterized by a shallow, linear response curve. To take advantage
25 of this feature, the photoresist is exposed through a variable transmittance mask. The mask has a variable transmittance function, $T(r)$. It produces, by exposure variation, an exposure pattern in the resist that is proportional to $T(x)$. The mask is produced via an e-beam, half-tone method. The combination of the photoresist having a shallow, linear response curve with exposure through a variable transmittance mask enables generating
30 the desired surface curvature of the microfresnel lens in the photoresist.

$$\phi(r) = \frac{2\pi}{\lambda} \left(\frac{r^2}{2R} \right) \quad (3)$$

$$\phi(r) = \frac{2\pi}{\lambda} \left(\frac{r^2}{2R} \right)$$

where the phase is measured from the center of the lens, at $r = 0$.

15 The microfresnel lens approach uses equation 3 to determine the grating spacing radii, r_i , by setting $\phi(r) = 1, 2, \dots, n$, out to the lens radius, r_0 . A nominal radius of curvature is desired that corresponds to a focal length equal to the cover glass thickness divided by its refractive index. For a 1.1 mm. thick glass, the focal length is 0.72 in air. In order to provide overall achromatic performance, the RGB lenses form a repeating
20 triad, each lens of the triad being positioned in accordance with its wavelength so that the focal length of the three colors are the same. For example, for the three wavelengths 460 nm, 540 nm and 620 nm, the radial positions of the first ring are, in the same order, 0.57 mm., 0.63 mm. and 0.67 mm. The required shape of the curve between each segment, r_i to r_{i+1} , is given by equation (1).

25 FIGURE 2 in the accompanying drawings is a schematic representation of an optical system; generally designated 10. Optical system 10 illustrates the function of the present microfresnel lens in enhancement of light transmission through a projection LCD.

30 System 10 includes a triad of microfresnel lenses 12 and a front panel glass 14 having an inner face 16. Color filters 18, to provide red, green and blue light, are applied on face 16. Light focused by lenses 12 passes through filters 18 and is focused

on apertures 20 on back panel 22. Panels 14 and 22 are joined by a seal 24 to form an enclosure 26 for the LCD fluid.

FIGURE 3 is a schematic representation of an alternative system 30 where light, split into red, green and blue light beams designated R, G and B, is directed through microfresnel lens 32, and focused through panel 34 on separate apertures 36 in panel 38. System 30 avoids a need for filters and lenses for each color. Light is transmitted as beams, but shown as rays to avoid confusion. The present microfresnel lens array is readily adaptable to either system.

The present invention is based on using an exposure through a single 5X mask to ultimately produce a lens element having the surface structure of a Fresnel lens. The 5X mask is desirable because of the 5X photoreduction in the exposure. We have found that a lens having the desired structure can be obtained by exposing, through a graded density transmittance mask, a positive photoresist that exhibits a shallow, linear response. Such a resist is available under the designation Shipley 1400-23, the resist essentially containing a novolak with hydroxy groups and a diazonaphthoquinone (DNQ). It has a shallow, linear response that can undergo a gradual, linear change in depth of exposure, rather than the usual sharp, steep change, when exposed through the variable exposure mask.

We achieve the desired lens structure by exposing a layer of positive photoresist through the graded transmittance mask. This generates a pattern of exposed resist having a surface boundary with unexposed resist that corresponds to the desired Fresnel pattern shown in FIGURE 1. We utilize an exposure mask with a variable transmittance function that provides the correct pattern of variable exposure to the resist. The desired surface configuration is obtained in undeveloped resist remaining on the substrate when the exposed resist is developed and removed. The resist lens may be hardened by appropriate post treatment such as deep UV or thermal baking.

A lens is produced through a one exposure process by preparing the photomask by e-beam writing in such a way as to provide the required gradient exposure. The desired focal length is determined by the ring spacing given by equation 3. The surface profile is produced by using a variable transmittance mask and a controlled uniform UV exposure. The transmittance function in the mask is produced by utilizing a half-tone

FIGURE 4 is an optical micrograph, taken at a magnification of 500 times, of a 5X mask prepared as just described. The dot density corresponds to desired transmittance intensity. The different optical densities were produced by controlling the exposure of a 5 pixel by 5 pixel element over sixteen elements. The size of the element was a function of the exposure. The resolution is such that when the exposure is made, the illumination pattern on the resist appears essentially continuous because of the 5X reduction in the exposure in the wafer plane.

FIGURE 4 is an optical micrograph, taken at a magnification of 500 times, of a 5X mask prepared as just described. The dot density corresponds to desired transmittance intensity. The different optical densities were produced by controlling the exposure of a 5 pixel by 5 pixel element over sixteen elements. The size of the element was a function of the exposure. The resolution is such that when the exposure is made, the illumination pattern on the resist appears essentially continuous because of the 5X reduction in the exposure in the wafer plane.

The glass substrate is then coated with an approximately 1.6 micron thick layer of a special resist that exhibits a shallow, linear response curve when developed. This linear behavior is a crucial property that enables producing the continuous surface figure in the resist. The resist coated glass is then exposed through the mask and the pattern developed in the resist. The optimum exposure is experimentally determined.

FIGURE 5 is based on an Atomic Force Microscopy (AFM) measurement showing a surface trace of a microfresnel lens configuration produced using a mask as shown in FIGURE 4.

FIGURE 6 is a photo taken by optical microscopy at a magnification of 250X. It shows a microfresnel lens array produced in accordance with the present invention. It illustrates the overall high efficiency achieved by a high fill factor, greater than 90%, a

very important aspect of the invention. It will be observed that partial lens elements extend into the four corners. This enables full utilization of the available space, and is a characteristic feature of the present lens array as envisioned by the term "high-fill factor."

5 The overall diffraction efficiency of the lens array was determined by measuring the increase in light through an LCD panel; that is, in the actual device setting. The lens array was placed into registration with the LCD panel shown in FIGURE 2. The panel was a fully assembled three-color dot panel with an unaided aperture ratio of 40%. The amount of light transmitted by a portion of the panel containing about 100 pixels
10 without the lens array was measured with a photometer attachment to a Nikon Optiphot™ microscope. The photometer was sensitive to the wavelength range encompassing the RGB lens. The lens array was then aligned to the panel with the lens surface against the outside face of the cover glass that had the aperture mask. The optical measurement with the photometer was repeated with the lens array in place. The
15 ratio of this reading with the lens array divided by the reading without the lens array from the previous measurement yielded the aperture ratio increase. The resist lens array provided an 80% increase in transmitted light through the LCD.

A microfresnel lens array, thus formed from photoresist, tends to be soft. It does not slump or flow, but it is vulnerable to damage during handling or in use. A serious
20 consideration, then, is providing a means of hardening or stiffening the photoresist to render it more robust. At the same time, the lens structure must remain essentially unchanged.

Various means of accomplishing this desired end have been devised. One method involves loading the photoresist with inorganic, colloidal particles prior to its
25 application to a surface. The amount of material mixed in the resist may be as much as is consistent with applying a thin layer.

A variation on this technique comprises using colloidal silica as the additive. A thin layer of the mix is applied and a microfresnel lens structure developed as described above. The lens pattern is then heated in air to remove the resist, thereby leaving a lens
30 structure of colloidal silica. This can be thermally coalesced, and further strengthened with an inorganic coating applied, for example, by CVD.

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and Si₃N₄ layer 400-500 Å on a glass substrate, we have found a clarity remains same at a temperature of 150-250° C., to be satisfactory. We have also deposited a SiO₂ layer, e.g., an 80 nm layer over the resist lens array. This hardened the surface, while having no adverse effect on optical performance.

For some purposes a lens pattern of photoresist can not be used. Rather, it may be necessary to have an all glass assembly. We have found that the photoresist lens pattern can be translated into a panel by uniformly etching the glass substrate bearing the resist lens until the resist is totally removed. Meantime, the pattern is transferred into the glass surface. This avoids the inherent absorption of the resist, thus enhancing the ultimate light output to about 90%.

Multicomponent glasses tend to etch non-uniformly. This may be avoided by depositing a silica layer on the glass surface prior to applying the resist and developing the microlens array therefrom. This permits the microfresnel lens array to be etched into the silica layer which tends to etch uniformly.

WE CLAIM:

1. A projection LCD comprising a glass panel and a transparent microfresnel lens array, the microfresnel lens array being in or on the glass panel and having a structural pattern of a Fresnel lens.
5
2. A projection LCD in accordance with claim 1 wherein the microfresnel lens array is on the glass panel surface and is composed of a positive photoresist having a shallow, linear curve response when exposed through a variable density mask.
- 10 3. A projection LCD in accordance with claim 2 wherein the photoresist microfresnel lens array is hardened.
4. A projection LCD in accordance with claim 1 wherein the microfresnel lens array is on the glass panel surface and is composed of a coalesced, transparent colloidal
15 inorganic oxide.
5. A projection LCD in accordance with claim 1 wherein the microfresnel lens array is in the glass panel and is composed of the panel glass.
- 20 6. A projection LCD in accordance with claim 1 in which each microfresnel lens in the array is aligned with a pixel in the LCD and has a fill factor greater than about 90%.
7. A projection LCD in accordance with claim 1 in which the focal length of the microfresnel lens equals the thickness of the glass panel.
25
8. A projection LCD in accordance with claim 1 wherein the microfresnel lens are arranged in triads and oriented with respect to the LCD pixels in a manner corresponding to the color wavelengths to correct for chromatic aberration.
- 30 9. A projection LCD in accordance with claim 1 wherein a layer of silica is applied to the glass panel and the microfresnel lens array is in such layer.

13. A glass LCD panel in accordance with claim 12 wherein the oxide is silica and the microfresnel lens array is in the glass panel and is composed of the panel glass.

15 14. A glass LCD panel in accordance with claim 13 wherein the oxide is silica.

15. A glass LCD panel in accordance with claim 10 wherein the microfresnel lens array is in the glass panel and is composed of the panel glass.

20 16. A method of increasing the amount of light transmitted through an LCD having a front glass panel which comprises producing on the front surface of the panel a microfresnel lens array composed of a positive photoresist in a structural pattern of a Fresnel lens.

25 17. A method in accordance with claim 16 which comprises producing the microfresnel lens array by applying a layer of a positive photoresist over the front surface of the LCD panel, and exposing the resist through a variable transmittance mask to produce an exposed portion in the photoresist layer having a structural pattern of a Fresnel lens.

18. A method in accordance with claim 17 which comprises developing and removing the exposed portion of the photoresist to leave a microfresnel lens structure on the LCD panel.
- 5 19. A method in accordance with claim 17 which comprises producing the variable transmittance mask by e-beam writing to impart to the mask a gradient transmission function corresponding to a curvature of a Fresnel lens.
20. A method in accordance with claim 19 which comprises producing the
10 transmittance function by a half-tone pattern generator that forms a range of small chrome dots by a standard e-beam process.
21. A method in accordance with claim 20 which comprises varying the areal density of the chrome dots as a function of the lens radius.
- 15 22. A method in accordance with claim 21 which comprises varying the chrome dot size in accordance with a segmented form of the equation
- $$h(r) = (\frac{1}{2}R_c) (r_0^2 - r^2)$$
- where "h" is the lens thickness, "r₀" is the lens radius and R_c is the radius of curvature.
- 20 23. A method in accordance with claim 18 which further comprises hardening the photoresist microfresnel lens.
24. A method in accordance with claim 23 which comprises hardening the
25 microfresnel lenses by exposing them to a deep UV cure.
25. A method in accordance with claim 23 which comprises subjecting the microfresnel lenses to a thermal treatment.
- 30 26. A method in accordance with claim 23 which comprises applying a thin inorganic film over the microfresnel lenses to improve durability.

31. A method in accordance with claim 29 which further comprises separating an inorganic oxide into, and on, the particle.

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32. A method in accordance with claim 17 which further combines etching the photoresist and panel to replicate the photoresist pattern into the glass surface.

33. A method in accordance with claim 18 which comprises applying a transparent
20 inorganic oxide layer on the glass panel prior to applying and developing the photoresist layer and then etching the photoresist pattern into the inorganic oxide layer.

34. A method in accordance with claim 16 which comprises producing the microfresnel lenses in triads in which each member is shaped to correspond to the
25 wavelengths of the primary colors-red, green and blue to correct for chromatic aberration.

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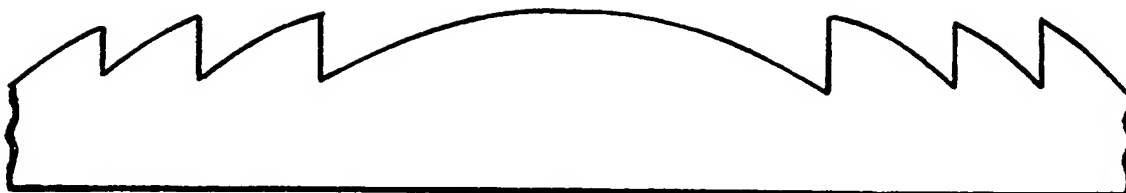


Fig. 1

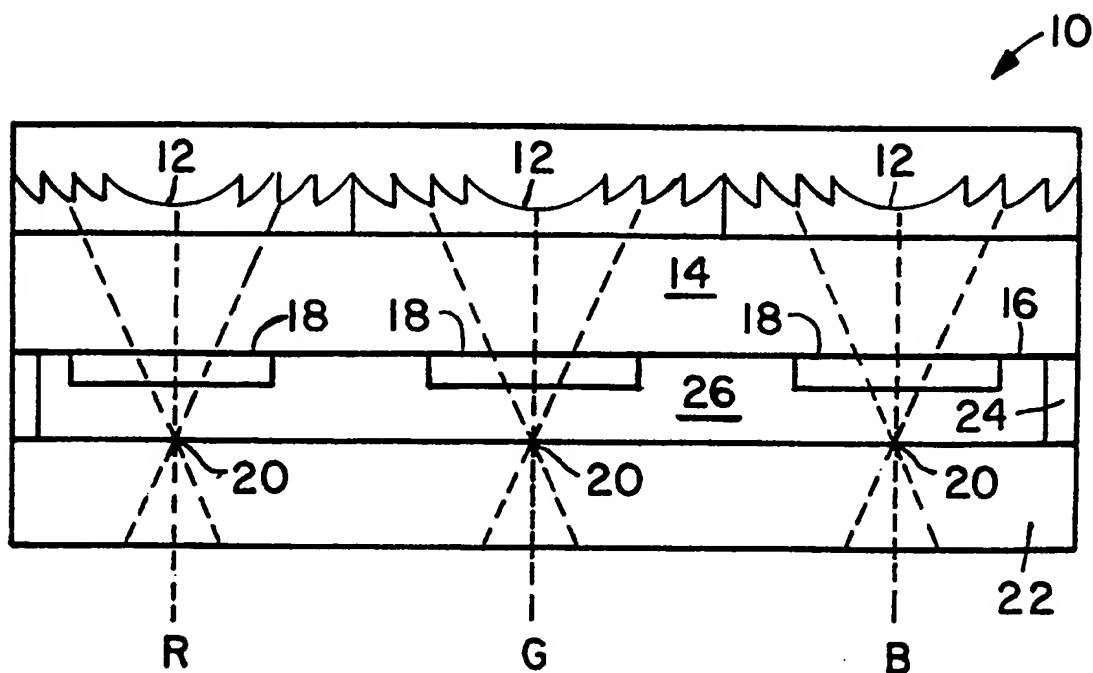


Fig. 2

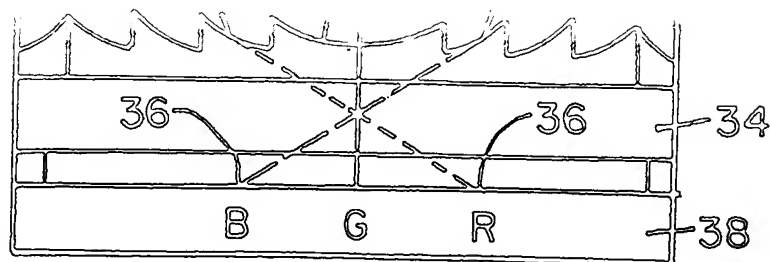


Fig. 3

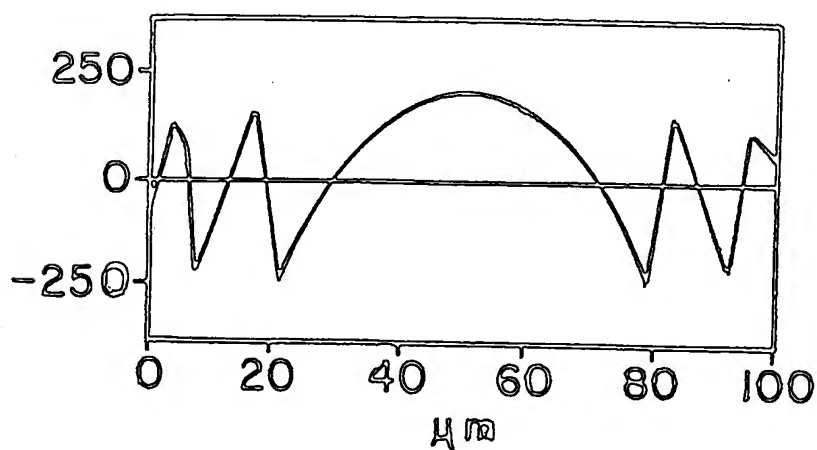


Fig. 5

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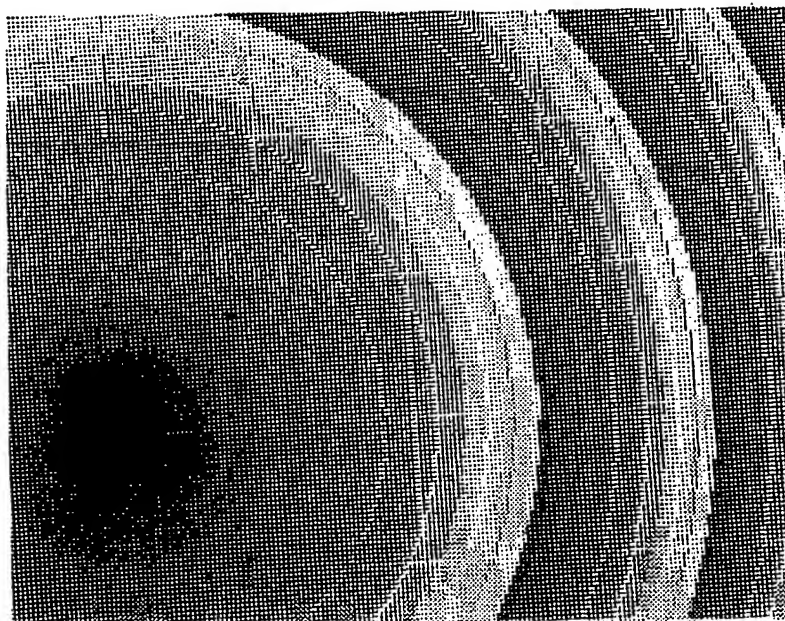


Fig. 4

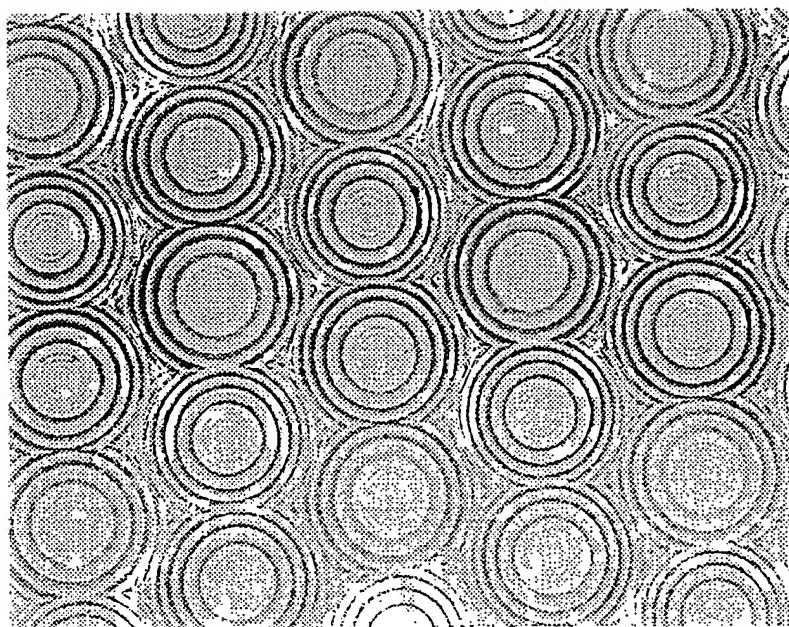


Fig. 6

<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.			
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Date of the actual completion of the international search 10 MARCH 1998	Date of mailing of the international search report 31 MAR 1998		
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer JAMES DUDEK <i>[Signature]</i> Telephone No. (703) 308-4093		